Program Objectives

1. Characterize the natural variation in community composition, distribution, and abundance of key species in sandy beach and rocky platform invertebrate and seaweed communities across years.
2. Characterize the natural variation in intertidal water and air temperatures along the entire Olympic coastline.
3. Monitor long-term trends in these parameters to detect significant changes and prompt targeted research to determine causes of stress and plan appropriate management actions.

Park ecologist conducting long-term monitoring of rocky intertidal community structure at Point of the Arches, Olympic National Park. Photo: NPS/OLYM

Intertidal Communities

THE MONITORING CREW MEMBERS MOVE LIKE GHOSTS THROUGH THE FOG, their felt-bottomed boots nearly silent on the barnacle-encrusted rocks jutting upward from the sea. The tidepools below brim with colonies of sea stars, mussels, anemones, and tube-worms. The team squints in the early dawn light, searching for tiny bolts in the rocks that mark the locations of their research plots, surrounded by the clattering sound of barnacles feeding and the rush of the rising tide.

This is the intertidal zone, one of the harshest and yet most fragile environments in the Inventory and Monitoring program. Its inhabitants constantly vie for space and food as their habitat submerges and reappears with every breath of the sea.

This harshness made it difficult to design a monitoring protocol for the intertidal zone, where the scientists' work follows the lowest tides, not Monday through Friday 9 to 5, and where low tides can occur at 3 a.m. To further understanding of this environment, National Park Service researchers track ocean and air temperatures and monitor community structure in sandy beach and rocky intertidal communities as part of the Inventory and Monitoring program.

The intertidal zone is a transitional region connecting marine and terrestrial environments. Submerged and exposed twice each day, it serves as a link between land and sea, and is therefore indicative of the health of both.

Intertidal zones are vital for the transfer of both nutrients and organisms between marine ecosystems and nearshore habitat. They are highly productive regions, fed by nutrient-rich water from deep sea upwellings and Puget Sound tidal currents and inhabited by the highest diversity of seaweeds and intertidal

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invertebrates on the west coast of North America. Pacific Northwest intertidal zones also feature a wide diversity of habitats, from Puget Sound's protected beaches to the cobble, sheer cliffs and wave-carved rocky platforms of the Olympic Coast. Intertidal zones are also highly sensitive to natural and anthropogenic disturbances from both land and sea, such as pollution, oil spills, and climate change, making them key locations for scientific monitoring.

Four parks within the North Coast and Cascades Network (NCCN) have coastlines with intertidal zones: Olympic National Park (Olympic), San Juan Island National Historical Park (San Juan), Ebey's Landing National Historical Preserve, and Lewis and Clark National Historical Park (Lewis and Clark). Currently, the intertidal monitoring protocol is being applied only at several sites within Olympic, San Juan, and Lewis and Clark.

Olympic National Park in northwestern Washington was established in 1938, and its intertidal zone was incorporated into the park in 1986. Olympic includes a 73-mile-long (117 km) strip of coastline along the Pacific Ocean, 75 percent of which is designated wilderness, the longest stretch of undeveloped coast in the contiguous United States. Its intertidal region is the most biologically and habitat-diverse park shoreline in the NCCN.

The intertidal zone at Olympic is what coastal ecologist and limnologist Dr. Steven Fradkin calls a "biodiversity hotspot," supporting more than 740 species of seaweed and invertebrates and more than 65 species of fish. These biological communities are important both ecologically and culturally, contributing to foodweb dynamics in the nearshore coastal ocean and providing subsistence and ceremonial resources for Native Americans and wilderness character appreciated by non-natives as well.

Seastars (*Pisaster ochraceus*) and the sea lemon nudibranchs (*Doris monteryensis)* on the bread crumb sponge Halichondria panicea near Point of the Arches, Olympic National Park.

The coast also features a wide variety of habitats, with rocky cliffs and benches, boulder fields, cobble fields, estuaries, and beaches of gravel or sand. The terrain changes every quarter of a mile in some places, Fradkin said.

This vast biodiversity led to the park's designations as both an international Biosphere Reserve and a World Heritage Site. This rare tract of undeveloped coastline functions as a "living laboratory," promoting conservation, research, monitoring, and education.

In 1988, following concerns about oil spills off the Olympic coast and in response to the need for baseline data about intertidal communities, Dr. Megan Dethier of the University of Washington Friday Harbor Labs established and refined sampling techniques for monitoring cobble, sand, and rocky habitats in Olympic's intertidal zones. In 1996, the NPS took on responsibility for this program and expanded its monitoring goals to look at community changes resulting from natural and anthropogenic factors, such as ocean acidification, sea level rise, temperature changes, and oil spills. Another academic research group, the Partnership for the Interdisciplinary Study of Coastal Oceans (PISCO), had recently established biodiversity monitoring sites within the park. When the NPS began designing and implementing the Inventory and Monitoring program between 2001 and 2005, it prioritized intertidal monitoring and built on this background, incorporating existing PISCO plots and creating its own sampling programs throughout NCCN parks with coastlines.

Monitoring Strategy

The main goal of this monitoring program is to detect substantial trends in air and water temperatures, community structure, and species abundance in sandy beach and rocky intertidal habitats. The protocol works as an early warning system, characterizing typical conditions for the intertidal zone and detecting both natural and human-caused changes. Unusual variations spur further studies that focus on why these changes are occurring, and help the NPS implement management strategies to address them. In the case of causes outside of the NPS's control, such as climate change and impacts of commercial fishing, the NPS hopes to use park data to help inform the public and alter behavior beyond park boundaries.

Marine parks dot the entire Pacific Coast of the continental U.S. Because these parks are located within different NPS Inventory and Monitoring Networks and have different resources at their disposal, they formed a "phantom" network to look for similarities between parks and programs to determine if any standard operating procedures (SOPs) could be implemented at each park to provide coast-wide comparisons. The phantom network includes the North Coast and Cascades, Klamath, San Francisco Area, and Mediterranean networks. To tie monitoring efforts together in these different networks, the

Park marine technician conducting long-term monitoring of sandy beach invertebrate community structure on Second Beach, Olympic National Park.

NPS incorporated a common SOP based on a previously existing, coast-wide monitoring network, the Multi-Agency Rocky Intertidal Network (MARINe).

Monetary and logistical constraints limited the scope, objectives and number of sites and habitat types that can be measured by the program. The extreme conditions experienced on the wave-swept open coast also made it difficult to design a monitoring program, Fradkin said. Researchers chose to concentrate on mid- to higher-elevation areas of intertidal zones because they are submerged 10-50 percent of the time (as opposed to low regions that are submerged for 90 percent of the time), increasing the amount of time available to conduct fieldwork.

“Neptune is a fickle master,” Fradkin said. “He doesn’t give us a lot of time to actually work in these places, because these intertidal areas are covered by water most of the time, but that curtain of water is pulled back twice a day.”

Data Collection

Intertidal field sampling in the NCCN occurs from May through the end of August because this is when the lowest tides of the year occur during daylight hours. Data collection consists of three components: intertidal temperature monitoring, sandy beach community monitoring, and rocky shoreline community monitoring. Community monitoring focuses on seaweeds and marine invertebrates and excludes intertidal fish and highly mobile invertebrates, such as shore crabs.

Intertidal Temperature Monitoring

Intertidal organisms are routinely submerged in seawater and exposed to air for varying periods of time. Temperatures in water and above the surface can alter physiological rates and exceed physiological tolerances of organisms, leading to changes in community structure. Water temperature is also indicative of the effects of climate change on the nearshore ocean.

To monitor fluctuating temperatures in such a harsh environment, research teams mount electronic data loggers on rocky substrates in the middle of intertidal zones in each marine park. These data loggers are approximately the size of five quarters stacked on top of each other and are encased in a protective housing to shield them from the elements. Like intertidal organisms, they spend some of their time inundated by water and some time exposed to the air. Glued with epoxy to tidepool rocks, the data loggers measure the time and temperature every half hour, year-round, providing a continuous record of air and water temperatures and a glimpse at the conditions that intertidal organisms face. Scientists download the data once a year, and replace the data loggers every four years.

Sand Beach Community Monitoring

Sand beaches make up 30 percent of the coastline in Olympic and are dominant habitats in the NCCN. They provide habitats for organisms living within sediments and are key resources for migrating birds, as well as playing an important role in nutrient cycling in the nearshore ocean. These habitats are highly susceptible to shoreline modification, oil spills and global climate change. The NPS's efforts are limited to beaches with fine-grained particles, excluding beaches with coarser-grained sand and gravels that require more time-consuming and complicated methodologies. For this reason, sand beach monitoring can only be conducted at fine sand beaches found at Olympic.

Each year, research teams establish three random transects at seven target beaches. Each transect is perpendicular to the shoreline and roughly 200 feet (60 m) long, starting at the high tide line. Approximately every 25 feet (7.5 m), researchers take four sediment cores and strain out, count and classify the organisms inside. Teams also collect sediment samples to determine the composition of the beach and survey the elevation profile of each transect to see how the slope of the beach changes between transects and over time. Changes in slope and elevation can impact how species are distributed across a beach, and slope can indicate whether a beach absorbs or reflects wave energy, factors that affect its composition and levels of biodiversity.

Rocky Shoreline Community Monitoring

As in mid-town Manhattan, space is a valuable resource in intertidal regions. In the rocky intertidal, organisms live in layers, like different floors in an apartment building. Different species live in parallel, horizontal bands with each band representing a different niche. A white stripe of barnacles plasters a rock above a dark band of mussels. Below them might be a red layer of algae or seaweed. These zonation patterns are caused by the organisms' physiological tolerances and their interactions with other species. The upper bounds of a layer are set by an organism's ability to tolerate physical conditions such as temperature or dryness. Species interactions, such as predation and competition, define the lower bounds. Predators such as the Ochre sea star (*Pisaster ochraceus*) feed on mussels but are uncomfortable in areas with higher temperatures that mussels can tolerate. This creates a horizontal line in elevation above which the sea stars will not venture and where the mussels thrive.

Approximately 21 percent of Olympic's coastline is composed of rocky shoreline. These areas are some of the most diverse ecosystems in the world, but are also very susceptible to effects of global climate change, oil spills, over-harvest and trampling.

To monitor rocky shoreline communities, research teams use targeted species plots that gather species numbers over a designated area and community plots that study specific areas in greater detail.

Targeted species monitoring plots are in fixed locations and focus on abundance of a particular group of organisms, in this case barnacles, mussels, and sea stars. Scientists place quadrats of plastic pipe frames with string stretched across in two directions over permanent bolts anchored into rocks, then look at the communities below. The strings on the plastic-framed quadrat make a grid, allowing researchers to divide the plot below and count the number of organisms within grid cells. Scientists also take additional data about individuals, such as the color of a sea star and the average length of its arms, and divide the organisms into classes by their abundance and size. Size relates to age and food availability and can indicate changes in a community.

Community monitoring plots are larger than targeted species plots and are based on different elevation transects within the intertidal zone. They allow scientists to monitor distribution of colonies and track changes in species zonation as communities move up and down in elevation on rocks over time. The plot locations are randomly selected and run approximately 33 feet (10 m) along the shore and as wide as necessary to incorporate high and mid intertidal zones. Teams divide the plot into smaller sub-quadrats and count the organisms found there.

Current Trends

The intertidal zone is an area Fradkin likes to call a "sentinel environment," making it an especially important ecosystem to monitor. These rare regions of undeveloped coastline sustain high levels of biodiversity and provide rich habitats for wildlife, but they are also some of the most likely first indicators for impacts of global climate change.

Organisms living in intertidal zones have adapted to battering waves, fluctuating temperatures, and fierce competition, but they aren't immune to disturbances caused by humans. Anthropogenic actions greatly impact the nearshore ocean and intertidal zones of the Pacific Northwest. Intertidal organisms require specific conditions to thrive. As climate and ocean processes change, some organisms exceed their physiological tolerances and die, while others move into new niches.

Climate change alone could change the face of the coast. Storm events could increase in size and frequency. Ocean acidity could rise with increasing carbon dioxide levels. Increases in air and water temperature could affect community structure and dynamics within the crowded intertidal zone. Sea levels are expected to rise roughly 2 to 43 inches (6 to 108 cm) by the year 2100, drastically altering the locations of intertidal zones. Sea levels on the coast of Olympic are predicted to range from approximately -9.5 to +35 inches (-24 to +88 cm), according to a 2008 report by the University of Washington Climate Impacts Group and Washington State Department of Ecology, as the landmasses at Olympic continue to uplift from tectonic activity and rebound after being depressed by the last ice age.

Other disturbances include the introduction of exotic species, shoreline modification, aquaculture and eutrophication—increasing levels of nutrients that can lead to algae blooms and declining oxygen levels. Oil spills are also of concern. All of the marine parks within the NCCN are along major commercial shipping routes for traffic, including oil tankers en route to ports in Portland, Oregon; Seattle, Washington; and Vancouver, British Columbia, Canada. Two recent spills occurred along the Olympic coast: The Nestucca in 1988 and the Tenyo Maru in 1991, both of which affected organisms along the Pacific coast.

"These organisms are living on a razor-thin threshold of physiological extremes, where the upper-boundary of organisms is based on how they can tolerate heat and how they can tolerate dryness—things that are likely to change with climate change," Fradkin said. "The lower boundaries are also set by biological interaction of organisms—competition, predation, these major, major interactions. The nature of those interactions can change drastically depending on environmental conditions. Warming, for instance, may actually physiologically stress certain organisms so that they're not very good at competing with other organisms. It might cause them to be more prone to predation., where they're not as fast. This can ripple through the entire foodweb."

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